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*Form Approved
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1. REPORT DATE (DD-MM-YYYY) 6 May 2003		2. REPORT TYPE Technical Abstract		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE The Effect of Pressure and Acoustic Excitation on Coaxial LN2/GN2 Jets				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) D. Davis, B. Cherhoudi, D. Talley				5d. PROJECT NUMBER 2308	
				5e. TASK NUMBER M13C	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) ERC, Inc. 10 E. Saturn Blvd. Edwards AFB CA 93524-7680				8. PERFORMING ORGANIZATION REPORT NUMBER AFRL-PR-ED-AB-2003-124	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S NUMBER(S) AFRL-PR-ED-AB-2003-124	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF: a. REPORT Unclassified			17. LIMITATION OF ABSTRACT A	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Sheila Benner
b. ABSTRACT Unclassified					19b. TELEPHONE NUMBER (include area code) (661) 275-5693
c. THIS PAGE Unclassified					

20030606 106

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

The Effect of Pressure and Acoustic Excitation on Coaxial LN₂/GN₂ Jets

Davis, D., Chehroudi, B., and Talley, D.

The present trend in liquid rocket engines, gas turbines, and Diesel engines, is towards increasingly higher chamber pressures. In many cases, the chamber pressure can exceed the critical pressures of the fuel or oxidant. Above the critical pressure, the distinction between the gas and liquid phases is lost, and mechanisms conventionally associated with subcritical spray combustion no longer necessarily apply. Until recently, relatively little has been understood about the injection and combustion behavior of propellants at supercritical chamber pressures. The results presented here are an extension of our previous work [1,2] systematically investigating liquid rocket injector behavior at subcritical and supercritical pressures. The injector for this work is a coaxial injector, with the center post being identical to that used in previous single round jet studies [1,2]. In this way, departures from single round jet behavior can be systematically explored. The center post of the coaxial injector has an inner diameter of 0.5 mm and an outer diameter of approximately 1.6 mm. The annulus gap is approximately 0.7 mm. The fluid issuing from the center post of the injector was liquid nitrogen (LN₂) at about 100K. Slightly warmer (~140K – 170K) and less dense ($\rho_l/\rho_g \sim 5 - 15$) gaseous nitrogen (GN₂) flowed from the annulus. The chamber was pressurized with GN₂ at ambient temperature. The effects of selected parameters are investigated, including the gas-to-liquid velocity ratio, mass flow rate ratio, different coaxial gases, and some geometrical parameters.

Preliminary calculations of the key operating parameters shows that velocity ratios (u_g/u_L) of the order of 10 and momentum flux ratios ($\rho_g u_g^2 / \rho_L u_L^2$) of about 3.5 are achievable using the present experiment. These values are similar to those of practical devices such as the Space Shuttle Main Engine (SSME) preburner, where $\rho_g u_g^2 / \rho_L u_L^2 \sim 3.45$ and $u_g/u_L \sim 10$ [3]. The coaxial jets are exposed to an acoustic field generated via a specially-designed piezo-siren, as described in refs. [2,4], capable of producing acoustical amplitudes of 180dB, with the strongest chamber resonances at 2.7 and 4.8 kHz. Thus the coupling of acoustic waves with jet process can be studied, having relevance to combustion instabilities in liquid rocket engines. Previous studies of acoustically excited single round jets with no coaxial gas flow [2] showed that at supercritical pressures the jet was relatively unaffected by the acoustic waves. However, more recent results where the coaxial gas flow was added [4] showed that the jets interacted with the acoustic waves even at supercritical pressures.

The principle diagnostic for this work is shadowgraph imaging using a model K2 Infinity long distance microscope fitted to a high resolution CCD camera by the Cooke Corporation. However, in addition to the shadowgraph data, preliminary laser-induced thermal acoustics (LITA) measurements are also presented. The LITA measurements provide a quantifiable measurement of the local speed of sound which can be related to temperature and density variations within the flow. Quantitative measurements have been made in the past [5] using a Raman technique, producing Raman intensities which are theoretically related to the density profiles. Representative results showing markedly different intensity profiles at subcritical and supercritical pressures are reproduced in Fig. 1. However, significant uncertainties in the Raman cross-section exist in the

supercritical regime. The LITA approach is an alternative technique which is expected to reduce the uncertainties associated with Raman measurements.

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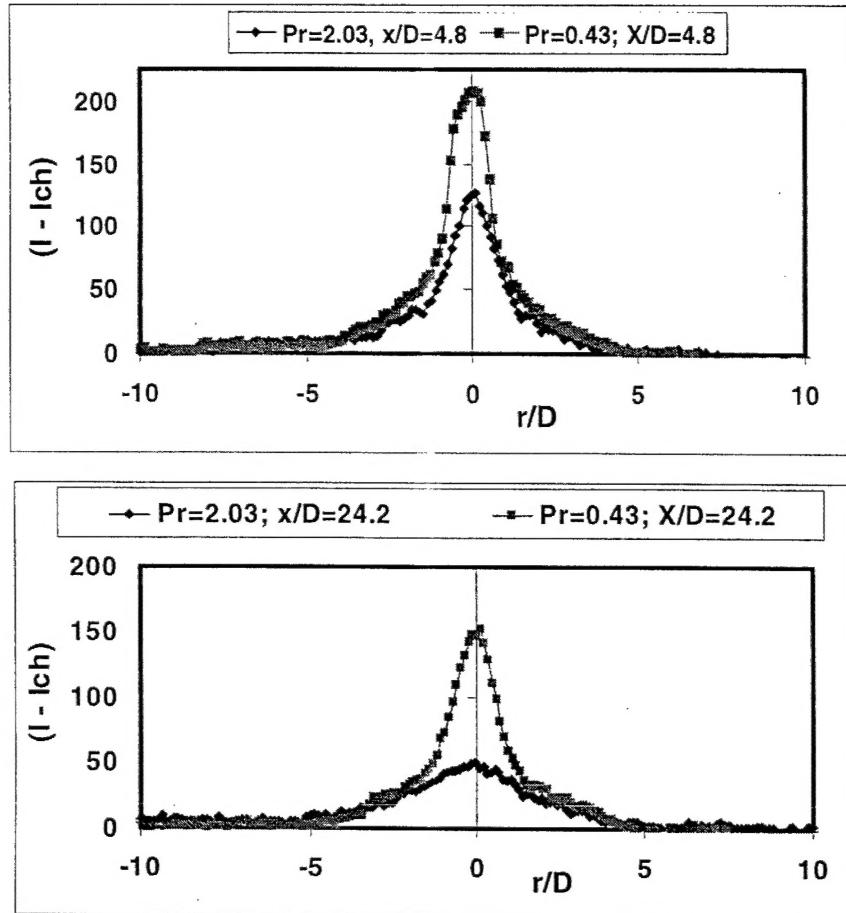


Figure 1. 40-frame-averaged Raman relative intensity radial profiles at two different axial distances from the injector and at sub- and supercritical chamber conditions. X and D are axial distance from the injector exit plane and injector hole diameter, respectively. I_{ch} stands for measured intensity sufficiently far from the jet location. The laser sheet propagation direction is from right to left. Pr is the reduced pressure, chamber pressure/critical pressure of N_2 . [5]